Available online at www.sciencedirect.com

SciVerse ScienceDirect

Energy Procedia 14 (2012) 235 – 240

Energy Procedia

International Conference on Advances in Energy Engineering (ICAEE2011)

Innovative patented PV/TH Solar Collector: optimization and performance evaluation

C.Cristofari, JL. Canaletti, G.Notton, C.Darras

University of Corsica, Pascal Paoli, UMR CNRS 6134, centre scientifique de vignola 20090 Ajaccio, France
Phone : +(33)4 95468375 e-mail: christian.cristofari@univ-corse.fr

Abstract

In the context of climate change in the world at the global level, various actions are taken for the development of Renewable Energy and particularly solar energy. Many technology solutions have been proposed such as solar hybrid collector whose objectives is to improve the PV panels performance by recovering heat looses with the heat removal fluid. The objectives of this article is to propose an hybrid photovoltaic-thermal collector manufactured in a polymer material twintex® patented by Saint-Gobin company, to have product lighter, cheaper and easier to handle. We expose the performance of this PV-T collector manufactured without air layer.

Keywords: Heating, Solar System, Photovoltaic supply, Solar Hybrid Collector PV-TH ;

1. Introduction

A solar heat collector can be combined with a photovoltaic module to form a mixed production unit generating simultaneously low temperature heat and electricity. Such solar collectors are named hybrid or combined photovoltaic-thermal collectors.

The solar energy is partially converted to electricity by photovoltaic cells generally in thermal contact with an absorber and the thermal energy generated by the photovoltaic cells serves as input for a thermal system.

These solar systems can be used for autonomous systems for preheated water, for grid connected applications and contractor PV. The aim is to increase efficiency of the solar collector by adding a

doi:10.1016/j.egypro.2011.12.887

function, PV or thermal function.

2. Description of the PV/T system

2.1 Original collector

We consider a classical solar water heating installation with the PV/T solar collector and a water tank for storage. A bypass is required which is controlled by a differential controller turning on the inlet fluid in the tank when the outlet fluid temperature of the collector is greater than the temperature of the fluid in the tank corresponding to the lowest temperature (at the bottom of the tank). If the outlet fluid temperature of the collector is lower than to the lowest temperature of the tank, the fluid return to the collector [1]

The PV/T collector is composed of a transparent cover, a double-glass polycrystalline module and an absorber-exchanger which transforms the solar radiation to heat. This system is without air layer. This “absorber-exchanger” has back and side insulations (expanded polyurethane), which is inserted in the body of the collector which allows a good mechanical behavior of the collector structure. The fluid is distributed uniformly under the surface of the absorber. The water flows are parallel. A header pipe supplies each pipe and another one collects the warm fluid. The pipes are connected to the system users. The absorber-exchanger in copolymer material, must satisfy the following constraints: UV protected, high thermal conductivity, water-resistant and glycol-resistant, good thermal range of utilization (-10/+150°C), a good mechanical strength and to be chemically stable. For our study, we selected the anti-UV treated polycarbonate which is the cheapest polymer and which satisfies chemical, mechanical and thermal constraints. We chose a single glass cover plate with a thickness equal to 4 mm.

3. Modelization

3.1 The PV/T solar collectors

The simulations is done by dividing the transversal section collectors into height and nine isothermal regions: the glass cover, the air layer (for the second type), 3 PV module parts (the top glass, EVA + silicon, the bottom glass), the top of the top half of the absorber, the water layer, the bottom half of the absorber and the insulation; therefore, we propose to dividing the length collector into ten sections fk in order to take into account the temperature distribution of the working fluid inside the collector.

These models also take into account the following input physical parameters: diffuse and direct solar irradiances Id and Ib, temperature of the ambient outside air Tae; temperature of the inside air Ta of the house; air velocity in front of the collector V ; sky temperature Tsky.

A heat balance is done for each region. In a previous work, the thermal behavior of the photovoltaic module (bi-glasses polycrystalline module) has been modeled and a experimental verification has been performed [5]. In this paper, all the hypothesis concerning the PV module modeling are explained. Concerning the polycarbonate solar thermal system, two previous papers show the various thermal hypothesis and the main results are shown [6-7].

3.2 The tank

Water tank may operate with significant degrees of stratification with the top of the tank hotter than the bottom. In our case, the tank will be modeled in i sections (I nodes), [8] with energy balances written for each section of the tank. All the hypothesis are presented in Ref [7].

3.3 Connection pipes

Modeling the connection pipes with insulation (e=3 cm) is simplified by considering the energy balance as a whole for the liquid returning from the load and returning from the collector. The temperature developments in the pipe connections are assumed linear (see [8]).

3.4 Method of solution

All the energy balances can be written in the guise of a differential matrix equation:

$$\left[C\right]\frac{d\vec{T}(t)}{dt} = \left[M\right]\vec{T}(t) + \left[S\right]\vec{E}(t) \quad (1)$$

T(t) is a vector containing system temperatures at *i* nodes of the mesh, [*C*] is a diagonal matrix with all the values of the thermal capacities of the material, [*M*] is a squared matrix with all the heat exchange coefficients between the elements of the mesh, [S] is a matrix which joins together the 5 input physical parameters (or excitations) expressed by the vector *E(t)* (I_b, I_d, T_{ae}, T_a, T_{sky}) and *i* elements of the mesh.

By solving the equations of this analogical model, we get directly the expression of the temperature for each nodes in function to the input parameters. This equation system is solved by the Runge Kutta Merson's method (order 4).

4. Results

The sizing must respond to the needs of hot water for 3 inhabitants in a Mediterranean site. Thus, we considered a collector with a surface of 2 m², a storage tank of 150 litres. The simulations have been performed with one year of real weather data. It is assumed that, in the early morning, the water inside the collector and all the parts of the collector follow the ambient temperature..

To take into account in the model the degree of tank stratification, it is necessary to divide the tank in a given number of nodes. Obviously, if the tank is fully mixed, the temperature at these various i nodes will be the same one whatever the number orifices of the manifold diffuser is.

A previous study [7] showed that to model correctly the stratification of the tank 10 nodes are necessary for the model of the tank.

All the next results concern the performances of the total solar system i.e. the hybrid solar collector with the tank, the pump, the pipes and the tank with the following geometrical configuration and for a given running mode (insulating thickness e=2 cm, flow rate = $2.65 \cdot 10^{-3}\mathrm{kg} \cdot \mathrm{m}^{-2} \cdot \mathrm{s}^{-1}$, fluid layer thickness equal to 1 cm, [9]) and for a stratified tank (10 nodes).

4.1 The tank temperatures and the thermal and electrical efficiencies.

The daily mean efficiency is given by the following relation [11] :

$$\eta_{day} = \frac{\sum qf}{A_c \int_{sunrise}^{sunset} I(t)\, dt} \quad (2)$$

where q_f is the thermal power produced by the hybrid solar collector, I the solar irradiance and A_c the solar collector area.

For the efficiency calculation, the most well-known model is given by the following equation :

$$\eta = \eta_{ref}\left[1-\beta_0\left(Tpv-T_{ref}\right)+\gamma LogI\right] \qquad (3)$$

where η_{ref} is the reference module efficiency at a PV cell temperature T_{ref} of 25°C and at a solar irradiance I on the module equal to 1000 W.m^{-2}. γ and β_0 are respectively the solar irradiance and temperature coefficients for the PV module. T_{pv} is the PV cell temperature which depends on the environmental conditions and which is computed in our simulation. The values of the coefficients are given and explained in ref [5].

According to Bergene and Lovvik [2], the total photovoltaic/thermal efficiency should be between 50 and 80% ; One should also take into account that the hybrid system generates electricity that has a much higher quality that heat. Thus, it is difficult to compare an hybrid system and a pure thermal solar collector as far as the qualities of the products are concerned. It should be also noted that increasing the high quality output (electricity) by increasing the flow rate leads to an even lower quality of the output heat (lower temperature) although the amount of heat itself increases. Taking quality factors into account is very difficult. Nevertheless, such considerations are necessary to characterize the hybrid system and its depend on the utilization of the system and on the energy having priority.

Many researchers [9,10,11] used the total system efficiency defined by:

$$\eta_T = \eta_{elec} + \eta_{ther} \qquad (4)$$

As previously underlined the value of electric power and thermal energy differs due to the form of energy. Electricity is a high-grade form of energy since it is converted generally from thermal energy. To take into account this consideration, Huang *et al* [4] suggest to use the energy-saving efficiency, in term of the primary-energy saving as :

$$\eta_{T,thermal} = \frac{\eta_{elec}}{\eta_{power}} + \eta_{ther} \qquad (5)$$

where η_{power} is the electric power generation efficiency for a conventional power plant taken equal at 0.38 [4].

In figure 1 (a), we have illustred for one year averages temperatures cells for PV system, PV/T system without air layer.

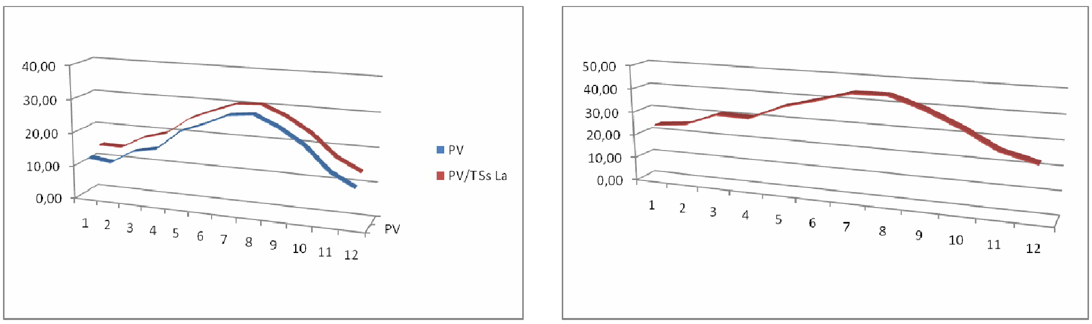

Fig. 1. (a) Evolution of average temperatures cells for different systems for each month; (b) Evolution of average temperatures tank for different systems for each month.

Max and Min average temperatures cells for PV system are 29.30°C and 11.29°C and 30.58°C and 13.69°C for the PV/T system.
In figure 1 (b), we have illustred for one year averages temperatures in tank. We note averages temperatures of tank which vary from 22.20°C to 44.30°C for PV/T system without air layer.
For PV/T system without air layer, the total efficiency according to eq. (4) is 43% and according to eq. (5) is 65%. We note that the electrical efficiency decreases during summer: the photovoltaic efficiency decreases when the temperature increases. But, in the same time, the thermal efficiency increases.

For PV/T system without air layer, the total efficiency is more important in summer than winter. On the year, the average efficiencies are : 29% for thermal one, 14% for PV one.
It is necessary to take into account that theses efficiencies are calculated for the hybrid solar collector in its environment i.e. with all the water heating system (pipe + tank) and consequently the efficiency is lower than it was computed in open circuit because the input water temperature in our conditions is greater, decreasing the global efficiency.
An experimental study has been performed by Tripanagnostopoulos *et al* [3] on hybrid collector using polycrystalline silicon cells and water as heat removing fluid, circulating through pipes with fins in contact with the back side of the PV module. They found 40% and 8.2% as thermal and electrical efficiency.

Huang *et al* [4] measured the various efficiencies and showed that the energy-saving efficiency exceeds 60% that is, larger than for a pure solar hot water heater.

4.2 Impact of the PV disconnecting power and stagnation temperature

In our study, the hybrid collectors reaches a stagnation temperature of 38.75°C at 820 W/m² at an ambient temperature of 15°C and in calm wind conditions (v = 0 m.s^{-1}).

In Figure 2, we present for one year various daily average parameters like pv cells temperature, water tank temperature, recovered thermal energy and lost electric energy when the PV panel is connected and disconnected. We can note 33% more for water tank temperature (33°C-24,9°C) and so 52% more for recovered thermal energy (4,6 kWh/day-3 kWh/day). We note 22% more for pv cells temperature (5,5°C-4,5°C).

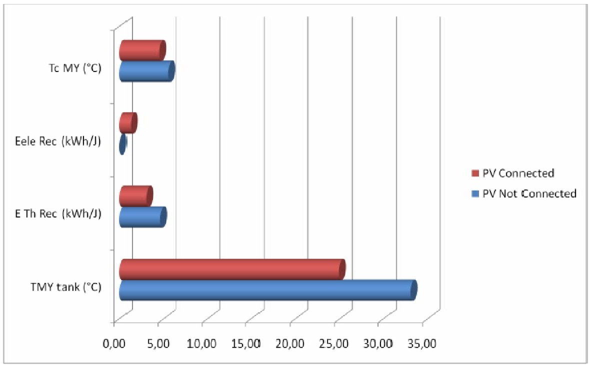

Fig. 2. Evolution of average daily like pv cells temperature, water tank temperature, recovered thermal energy and lost electric energy when the PV panel is connected and disconnected for one year.

5. Conclusion

In this paper, research complementary to research published earlier [12], we illustrated the thermal behavior of a solar water heating systems using a hybrid PV/thermal collector in regard to radiative conditions. We chose a copolymer material for the ‘absorber-exchanger’ satisfying chemical, thermal and mechanical constraints: the polycarbonate Twintex®. We developed a nodal model for the solar water heating installation and studied different temperatures evolution of solar collector and storage fluid. We obtained average efficiencies equal to 29% for thermal one, 14% for PV one, 43%-65% for respectively using total system efficiency and energy-saving efficiency. We note the importance of thermal recuperation which can catalyze development of these systems. The utilization of a copolymer for the total design of the solar collector has the advantage of reducing the weight by more half in comparison with a traditional collector using essentially metals with similar performances.

References

[1] M. Chateauminois, D. Mandineau, D. Roux, Tableau des températures du réseau eau froide Calcul d’installations solaire à eau, Collection de l’ESIM Edition EDISUD, 1979.

[2] Bergene, T., Lovvik, O.M.. (1995). Model calculation on a flat-plate solar heat collector with integrated solar cells. Solar Energy 55(6), 453-462.

[3] Tripanagnostopoulos, T., Nousia, Th., Souliotis, M. (2000). Low cost improvements to building integrated air cooled hybrid PV-Thermal systems. Proceeding of the 16th EPSE conference, Glasgow, UK, 1-5 May 2000, pp. 1874-1877.

[4] Huang, B.J., Lin, T.H., Hung, W.C., Sun, F.S. (2001). Performance evaluation of solar photovoltaic/thermal systems. Solar Energy, 70-5, 443-448.

[5]G. Notton, C. Cristofari, M. Mattei, P. Poggi, “Modelling of a double-glass photovoltaic module using finite differences”, Applied Thermal Engineering, 25-17-18, pp. 2854-2877, 2005.

[6] C. Cristofari, G. Notton, P. Poggi, A. Louche, “ Modelling and performance of a copolymer solar water heating collector “, Solar Energy, 72-2, pp. 99-112, 2002.

[7] C. Cristofari, G. Notton, P. Poggi, A. Louche, “Influence of the flow rate and the tank stratification degree on the performances of a solar flat-plate collector “, Int. J. of Thermal Sciences, 42-5, pp. 455-469, 2003.

[8] J.A. Duffie, W.A. Beckman, Solar Energy Thermal Processes, 2nd Edition, Wiley–Interscience, New York, ISBN 0-471-51056-4., 1991.

[9] T. Bergene, O.M. Lovvik, “Model calculation on a flat-plate solar heat collector with integrated solar cells”, Solar Energy 55(6), pp. 453-462, 1995

[10] H.P Garg, R.K Argawal, A.K Bhargava, “The effect of plane booster reflector on the performance of a solar air heater with solar cells suitable for a solar dryer”, Energy Conversion and Management, 32, pp. 543-554, 1991.

[11] T. Fujisawa, T. Tani, “Binary utilization of solar energy with photovoltaic thermal hybrid collector”, Proc. ISES Solar World Congress, 2, pp. 559-564, 1997.

[12] C.Cristofari, G.Notton,J.L.Canaletti, Thermal behaviour of a copolymer PV/Th solar system in low flow conditions, Solar Energy, pp 1123-1138, 2009.